Influence of sediment characteristics on the composition of soft-sediment intertidal communities in the northern Gulf of Mexico

Kyle E Coblentz, Jessica R Henkel, Bryan J Sigel, Caz M Taylor

Benthic infaunal communities are important components of coastal ecosystems. Understanding the relationships between the structure of these communities and characteristics of the habitat in which they live is becoming progressively more important as coastal systems face increasing stress from anthropogenic impacts and changes in climate. To examine how sediment characteristics and infaunal community composition were related along the northern Gulf of Mexico coast, we sampled intertidal infaunal communities at seven sites covering common habitat types at a regional scale. Across 69 samples, the communities clustered into four distinct groups on the basis of faunal composition. Nearly 70% of the variation in the composition of the communities was explained by salinity, median grain size, and total organic content. Our results suggest that at a regional level coarse habitat characteristics are able to explain a large amount of the variation among sites in infaunal community structure. By examining the relationships between infaunal communities and their sedimentary habitats, we take a necessary first step that will allow the exploration of how changes in habitat and community composition influence higher trophic levels and ecosystem scale processes.

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Introduction

21   Coastal habitats are among the most productive and threatened on Earth and the benthic

22 infauna, the organisms inhabiting the matrix of sediment of these habitats, are important

23 constituents of the ecosystem. Benthic infauna are responsible for a significant amount of

24 sediment bioturbation, secondary productivity, and nutrient cycling (Graf & Rosenberg 1997).

25 Therefore, cultivating an understanding of the links between benthic infauna and their habitats is

26 an important step in working towards understanding how alteration and degradation of these

27 habitats may influence the functioning of coastal ecosystems.

28   The soft-sediment intertidal habitats of the northern Gulf of Mexico coast provide a system

29 for understanding community/habitat relationships and their implications for larger scale

30 processes. The intertidal infaunal communities along the northern Gulf of Mexico coast are

31 relatively understudied (but see Shelton & Robertson 1981; Rakocinski et al. 1991; Dubois et al.

32 2009) despite being an important resource for many species, including threatened migratory

33 shorebirds, a variety of fishes and economically important invertebrates (Gloeckner &

34 Luczkovich 2008; Henkel, Sigel &Taylor 2012; Hsueh, McClintock & Hopkins 1992; McTigue

35 & Zimmerman 1998; Quammen 1984). The habitats of these communities are experiencing

36 unprecedented geological and anthropogenic changes. Modifications to the flow of the

37 Mississippi River have led to drastic changes in the coastal geology of the Mississippi deltaic

38 region and surrounding areas (Day et al. 2007), and has also resulted in the highest rates of

39 relative sea-level rise globally (Penland & Ramsey 1990, Zervas 2009). Moreover, in 2010 the

40 region was affected by the Deepwater Horizon oil spill, the largest oil spill in United States

41 history (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling

42 2011). But understanding how infaunal communities fit into this framework of change and the

43   potential for larger scale consequences at the ecosystem level requires a baseline understanding

44   of the relationships of communities to their habitats.

45   It has long been recognized that sediment characteristics greatly influence the structure and

46   diversity of benthic infaunal communities (Gray 1974). Relationships between sediment

47   characteristics and infaunal communities have been studied in a variety of habitats and scales.

48   Sediment grain size, organic content, food abundance, water depth, habitat structure, and salinity

49   have all been shown to influence the composition of infaunal communities (e.g. Ellingsen 2002;

50   Lindegarth & Hoskin 2001; Mannino & Montagna 1997; Thrush et al. 2001; Van Hoey, Degraer

51   & Vincx 2004; Ysebaert & Herman 2002). The relative importance of each of these factors

52   varies widely between studies, and these differences may be related to the habitat types, scale,

53   and variability of the environmental factors in the systems being examined. Therefore,

54   developing our understanding of infaunal community composition's relationship to habitat

55   characteristics in habitats for which these relationships have yet to be determined is necessary

56   before larger scale processes can be examined.

57   Here we examine invertebrate communities at seven intertidal sites along the north central

58   coast of the Gulf of Mexico representing common coastal habitat types at sites spanning a

59   regional scale. Our aim is to explore the relationships between infaunal community structure and

60   sediment characteristics to determine the environmental factors most important in structuring the

61   communities at a regional scale. We focus on the top 5 cm. of sediment in these habitats, the

62   depth to which cores were taken by the United States Geological Survey sampling intertidal

63   invertebrates prior to landfall of the Deepwater Horizon Oil Spill in 2010 (Demopoulos & Strom

64   2012), and the depth most likely to have the highest productivity and influence on higher trophic

65   levels (Rodil et al. 2008).

66   **Methods**

67   *Field-site Description*

68   We collected samples from seven intertidal sites along the northern Gulf of Mexico from

69   Louisiana to Alabama (Fig. 1). Our westernmost site, CAM, was located at Broussard's Beach

70   (29°45'57.6"N, 93°16'58.8"W), in Cameron Parish, Louisiana. CAM is located near the mouth of

71   the Calcasieu River, which provides freshwater input. The habitat at this site is a sandy beach

72   composed of fine-grained sand with small fragments of shell hash. Two sites, ELMBB

73   (29°7'51.6"N, 90°11'42.0"W) and ELMS (29°11'42.0"N, 90°04'22.8"W) were located on the

74   nearshore barrier island, Elmer's Island, Louisiana. ELMBB is on the back bayside of the barrier

75   island. The habitat is characterized by standing water, which is replenished by tidal inundation.

76   The sediment of ELMBB is composed of mud and fine-grained sand topped by a thin algal mat.

77   ELMS is located on the Gulf of Mexico side of the island, and is a fine-grained sand beach.

78   Freshwater input to Elmer's Island is provided by Barataria Bay and the Mississippi River.

79   Samples from site WAVE were collected at Waveland Beach, Mississippi (30°19'01.2"N,

80   89°01'58.8"W), a sandy beach near the mouth of Bay St. Louis that is composed of medium-

81   grained sand, some of which is dredged from nearby and periodically added to the beach. OS is a

82   remnant wetland site at Ocean Springs, Mississippi (30°22'58.8"N, 88°48'36.0"W). The sediment

83   in the remnant wetland consists of both mud and medium-grained sand and contains the roots of

84   dead vegetation. Freshwater input to OS is provided by Biloxi Bay. Two more sites, DIS

85   (30°15'10.8"N, 88°11'56.4"W) and DIP (30°15'.00.0"N, 88°11'56.4"W), were on the barrier

86   island, Dauphin Island, Alabama. DIS samples were collected from the bay side of the island,

87   which consists of a sandy shoreline of large-grained sand. The bay side pool habitat, DIP, is

88   characterized by standing water that is replenished by tidal inundation. The sediment at DIP is

89   layered with an algal mat that traps smaller sediment particles lying above a layer of large

90   grained sand. Freshwater input to Dauphin Island is provided by Mobile Bay. All sites have

91   variable salinity dependent on recent weather conditions and the amount of freshwater input

92   provided by nearby rivers and bays.

93   *Field and laboratory methods*

94   We collected sediment cores from the intertidal area that is a consistently inundated under

95   normal tidal cycles and weather conditions to determine sediment characteristics and infaunal

96   invertebrate community composition at each site. Ten cores were collected from each site except

97   for ELMS where one sample was lost. Samples were collected between 24 March 2012 and 6

98   April 2012 using a PVC corer 5 cm deep and 10 cm in diameter. The sediment collected was

99   placed into glass jars which were kept on ice until the samples were returned to the lab. After

100 being returned to the lab the samples were stored at -30°C until processing.

101 In the laboratory, each sediment core was homogenized and approximately 30g of sediment

102 from each core for a given site was placed into a composite sample and was stored at -30°C for

103 later sediment analysis. The remainder of the sediment from each core was sieved through a

104 500μm mesh and the material remaining on the mesh was placed in a mixture of 95% ethanol for

105 preservation and 10% Rose Bengal dye to improve sorting of invertebrates. Using a dissecting

106 microscope, invertebrates were sorted and identified. Infaunal invertebrates were mostly

107 identified to family except for members of Platyhelminthes and Nemertea which were identified

108 to phylum, Bivalvia, Gastopoda and Oligocheata which were identified to class and Coleoptera

109 which were identified to order. Invertebrates were not identified to lower levels of classification

110   due to taxonomic uncertainties and to avoid complications arising from using disparate levels of

111   classification.

112   The composite sediment samples were analyzed for total organic content (TOC), pore water

113   salinity, median grain size and the grain size coefficient of variation. TOC was determined for

114   each site by first drying approximately three grams of sediment in a muffle oven at 60°C for 14

115   hours and then burning the sample at 450°C for six hours; TOC was calculated as the percent

116   weight lost between the dry and burned sediment. To obtain pore water salinity, pore water was

117   extracted from the sediment in the lab and salinity was measured using a salinity refractometer.

118   Median grain size and grain size coefficient of variation were measured using an LS 13 320

119   Laser Diffraction Particle Size Analyzer. Details on the methods used for obtaining the grain size

120   distribution using laser diffraction can be found in Coblentz et al. (2014).

121   *Statistical methods*

122   Abundance of invertebrates (individuals of each taxon/0.08 m^2) was calculated after pooling

123   the 10 sub-samples per site, excepting ELMS where 9 samples were pooled (0.071 m^2). For each

124   site, taxa accumulation curves were plotted and visually assessed to ensure that each community

125   had been adequately sampled (Fig. 2). To examine the relationships between environmental

126   variables and invertebrate community composition, the matrix of square root transformed taxa

127   abundances for all sub-samples was used with non-metric multidimensional scaling (NMDS;

128   Clarke & Warwick 2001) using the Bray-Curtis dissimilarity index to group sites according to

129   community composition. The ordination results were plotted and examined for any clear

130   groupings among sites. Analysis of similarity (ANOSIM) was applied post hoc to test for

131   significant differences between hypothesized groupings. To analyze the relationships between

132 community composition and sediment characteristics, the *bioenv* function was used in the R

133 package *vegan* (Oksanen et al. 2011, vegan, v. 2.0-2). This function provides the subset of

134 variables that has the highest Spearman Rank Correlation Coefficient with the Bray-Curtis

135 dissimilarity index (Clarke & Ainsworth 1993). For each of the variables selected by the *bioenv*

136 function, a smooth surface representing the environmental variable was overlaid onto the NMDS

137 using the *ordisurf* function in the R package *vegan* (Oksanen et al. 2011, vegan, v. 2.0-2). This

138 procedure develops a visual representation of the relationships between community composition

139 and sediment characteristics. All statistics were performed in R (v2.14.2; R Development

140 CoreTeam 2012).

141   **Results**

142   Invertebrates representing five phyla, seven classes, and fifteen families were identified

143 across the 69 sediment cores (Table 1). The invertebrate communities from our seven sites were

144 clustered into four distinct groupings (Fig. 3A; stress = 0.04; ANOSIM, R = 0.9989, p = 0.001).

145 Our only remnant wetland site, OS, was a unique community and was dominated by tube-

146 building tanaid crustaceans, but had high taxonomic richness including four families of

147 polychaetes, three families of amphipods, and bivalves. 83.6% of the abundance consisted of

148 tanaids, followed by 12.5% corophiid amphipods, and 3% polychaetes. The remainder was

149 composed of gammarid and ischyocerid amphipods, the isopod family Idoteidae, and bivalves.

150 The sandy beach habitat at DIS was also a unique community and was dominated by interstitial

151 oligochaetes and nemerteans, with a low abundance of interstitial platyhelminths. The two back-

152 bay pool sites, DIP and ELMBB, formed a cluster due to similar communities dominated by

153 ephydrid fly larvae, which composed 92% of the abundance at ELMBB and 66.5% of the

154 abundance at DIP. The remainder of the abundance at ELMBB consisted of insect larvae adapted

155 to salt marsh conditions. At DIP, 20.2% of the remaining abundance was composed of insect

156 larvae adapted to salt marsh conditions and 13.2% of the abundance was composed of capitellid

157 polychaetes and oligochaetes. The three remaining ocean-side beach sites, CAM, ELMS, and

158 WAVE, also formed a cluster and had similar communities dominated by haustoriid amphipods

159 (96.5, 97.4, and 97.2% of the abundance respectively) with a small number of bivalves.

160   The model of environmental characteristics with the highest Spearman Rank Correlation to

161 the dissimilarity matrix included a combination of salinity, median grain size and organic content

162 (*bioenv*, $\rho = 0.67$, Fig. 3A, Fig. 4). Salinity was highest in the pool habitats, DIP and ELMBB,

163 and was well over the salinity of seawater, while salinity at the other sites ranged from 14 to 5

164 (Fig. 3B,Fig. 4). Sediment median grain size was highest at DIS and lowest at OS, although OS

165 had a high coefficient of variation in grain size (Fig. 3C, Fig. 4). TOC was highest at OS and was

166 lower at all other sites, and was particularly low at DIS (Fig. 3D,Fig. 4).

167   **Discussion**

168   Previous studies have related benthic invertebrate community structure to several habitat

169 characteristics with a relatively wide range in the explanatory power of the environmental

170 variables measured (e.g. Ellingsen 2002; Lindegarth & Hoskin 2001; Mannino & Montagna

171 1997; Thrush et al. 2001; Van Hoey, Degraer, & Vincx 2004; Ysebaert & Herman 2002). Here

172 we examined intertidal macrobenthic communities at sites covering common habitat types across

173 a broad geographic region. The communities clustered into four distinct groups, although local

174 variation in abundances of community members was evident. Nevertheless, nearly 70% of

175 variation in the communities between sites was explained by salinity, median grain size, and

176 organic content.

177   The clustering of communities observed in our data is related to coarse habitat

178   characteristics, which are reflected quantitatively by the sediment characteristics measured. For

179   example, the two pool sites, ELMBB and DIP, clustered together in community composition due

180   to dominance of salt-tolerant insect larvae. This result is not surprising due to high pore-water

181   salinity measurements in both of the pool habitats, likely from the evaporation of water in the

182   pools. Similarly, presence of the roots of dead vegetation at the remnant wetland site OS

183   provides a unique habitat characteristic among the sites we examined. In turn this habitat

184   characteristic is reflected in the high TOC measurements from the sediment cores at OS. Hence,

185   the three sediment variables included in the model for explaining variation in community

186   composition across sites appear to provide a good quantitative description of the coarse habitat

187   characteristics leading to differences between sites. Similar results have been found in other

188   studies where general sediment characteristics, such as percent mud or silt-clay, explain a large

189   component of the variation in infaunal community composition (Ellingsen 2002; Ysebaert &

190   Herman 2002).

191   Sediment grain size coefficient of variation was measured, but was not included in the model

192   explaining the largest amount of variation in community composition. However, in another study

193   we showed that sediment grain size coefficient of variation was a significant explanatory factor

194   in the taxonomic richness of these communities (Coblentz et al. 2014). This suggests that the

195   variables related to community composition at the regional scale we examined may not be the

196   same as those that are related to diversity in the same communities. In fact, Shannon's diversity

197   was low across all sites and was not associated with any of the environmental variables

198   measured. DIP had the highest evenness of the sites examined, while the remaining sites were

199   dominated by one or a few taxa contributing to relatively low Shannon's diversity values (Figure

200   4). The dominance of one or a few taxa in benthic intertidal habitats has been observed in similar

201   studies and provides an explanation for the low Shannon's diversity values and the variability

202   observed across communities (e.g. Shelton & Robertson 1981, Ysebaert and Herman 2002).

203   Despite the geographic distances among sites, our data show that sediment characteristics are

204   still able to explain a differences in invertebrate community structure among habitat types. This

205   result is promising for the management of coastal habitats and ecosystems along the northern the

206   Gulf of Mexico. Our results suggest that, rather than needing detailed information on a variety of

207   different environmental variables, knowledge of a few general habitat characteristics is sufficient

208   to predict the "type" of invertebrate community present in a given habitat. The association of

209   community composition to habitat characteristics facilitates a predictive framework of how

210   communities might respond to both natural and anthropogenic changes in habitat characteristics.

211   Although it is unlikely that infaunal invertebrates will be managed directly, their trophic link to

212   ecologically and economically important shorebirds, fishes and invertebrates makes the

213   knowledge of infaunal invertebrate habitat associations an important endeavor (Gloeckner &

214   Luczkovich 2008; Henkel, Sigel & Taylor 2012, Hsueh, McClintock & Hopkins 1992, McTigue

215   & Zimmerman 1998, Quammen 1984).

216   As coastal ecosystems continue to face pressures due to global climate change and

217   anthropogenic impacts, understanding how communities of organisms are associated with

218   components of their habitats is important to predict and understand how ongoing and future

219   changes are likely to shape the functioning and composition of coastal ecosystems. Here we

220   establish a baseline for this goal in the northern Gulf of Mexico by examining the relationships

221   between infaunal invertebrate communities and the sediment in which they live. To build on this

222   baseline, we suggest that further research examine the ecosystem functions provided by the

223 infauna in different habitat types such as secondary production, bioturbation and nutrient cycling

224 and how these functions are likely to change in response to predicted changes in coastal

225 gemorphology and land use. Research along these lines will help us to understand how future

226 changes will not only affect communities of infaunal invertebrates, but, through their ecosystem

227 functions, their impact on higher trophic levels and the coastal ecosystem as a whole.

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Community composition of infaunal invertebrates.

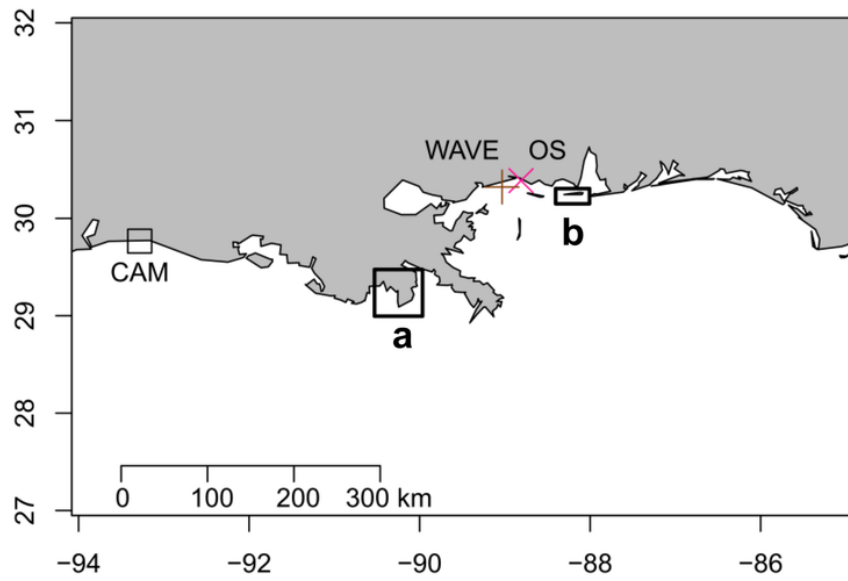
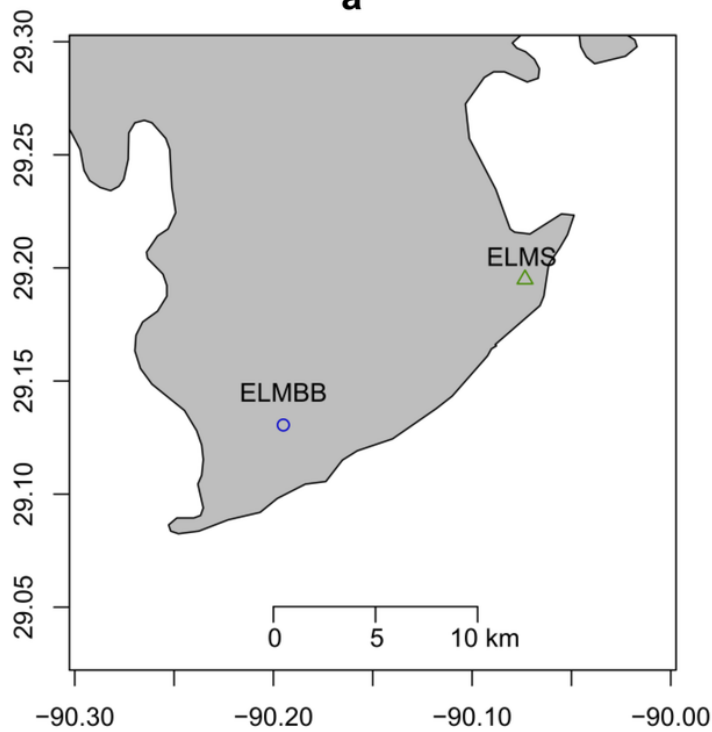
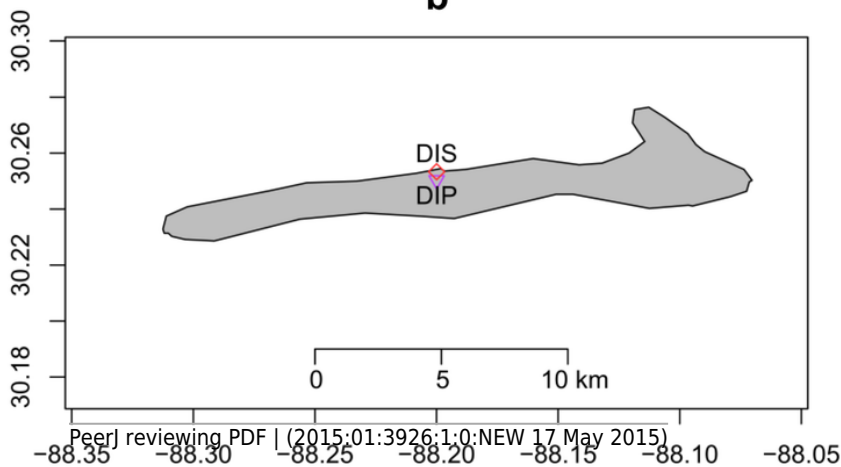
Invertebrate abundance per 0.08 m^2 except ELMS where abundance per 0.071 m$^{2.}$ is reported.

Taxa							
Arthropoda							
Amphipoda	CAM	ELMS	ELMBB	WAVE	OS	DIP	DIS
Corophiidae	0	0	0	0	806	0	0
Gammaridae	0	0	0	2	13	0	0
Haustoriidae	397	571	0	352	0	0	0
Ischyoceridae	0	0	0	0	1	0	0
Tanaidacea							
Leptocheliidae	0	0	0	0	5410	0	0
Isopoda	-	-	-	-	-	-	-
Idoteidae	0	0	0	0	6	0	0
Insecta	-	-	-	-	-	-	-
Ephydridae	0	1	562	0	0	499	0
Tabanidae	0	0	34	0	0	126	0
Dolichopodidae	0	0	7	0	0	8	0
Ceratopogonidae	0	0	0	0	0	1	0
Coleoptera	0	0	3	0	0	17	0
Annelida							
Polychaeta							
Nereidae	0	0	0	0	82	0	0
Capitellidae	1	0	0	0	123	67	0
Phyllodocidae	0	0	0	0	5	0	0
Spionidae	0	1	0	0	4	0	0
Orbinnidae	0	1	0	1	0	0	0

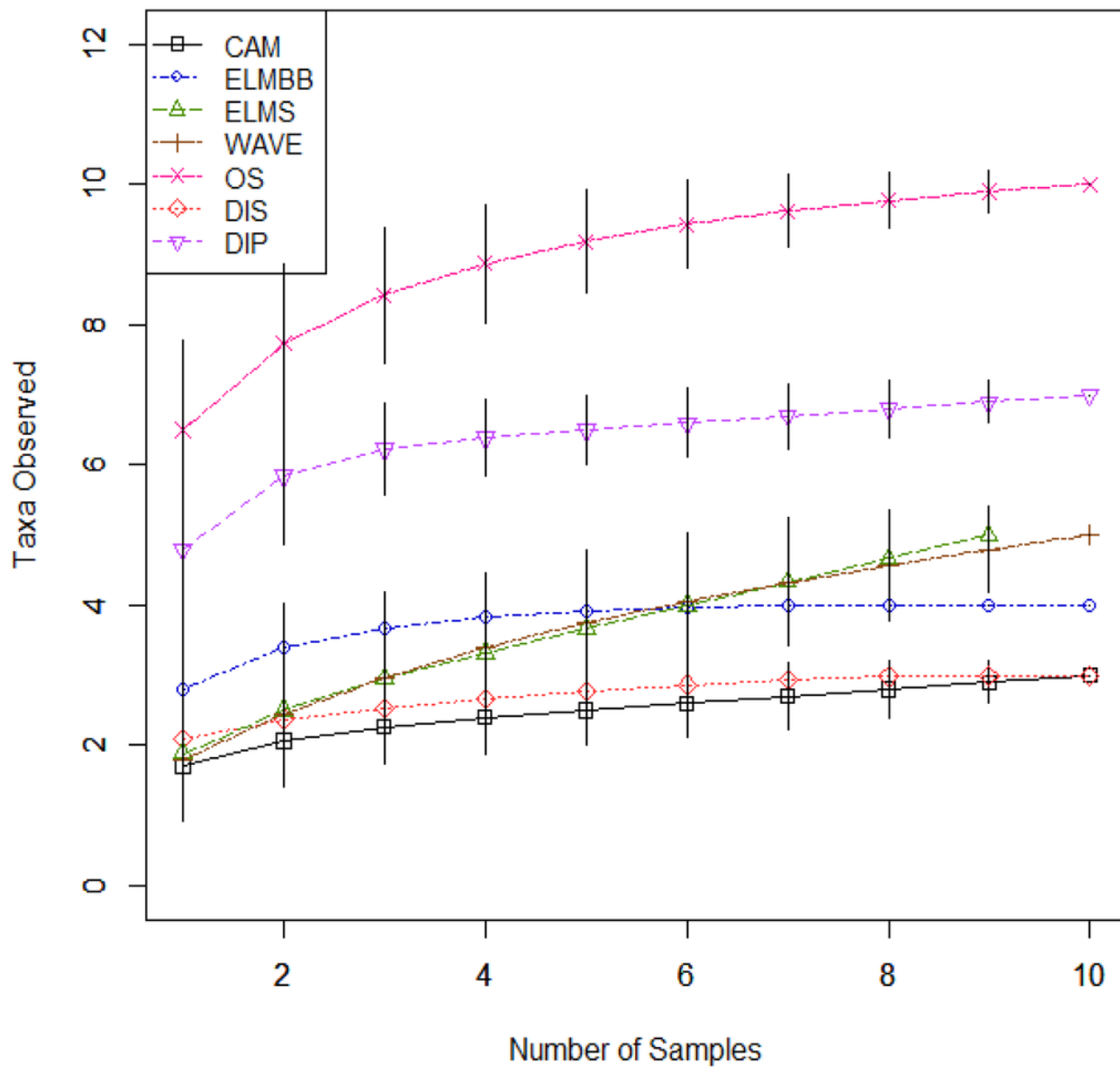
		Oligochaeta	0	0	0	0	0	32	644
	Nemertea		0	0	0	0	0	0	74
	Platyhelminthes		0	0	0	0	0	0	6
	Mollusca								
		Bivalvia	13	12	0	4	17	0	0
		Gastropoda	0	0	0	3	0	0	0
		TOTAL	411	586	606	362	6467	750	724

1

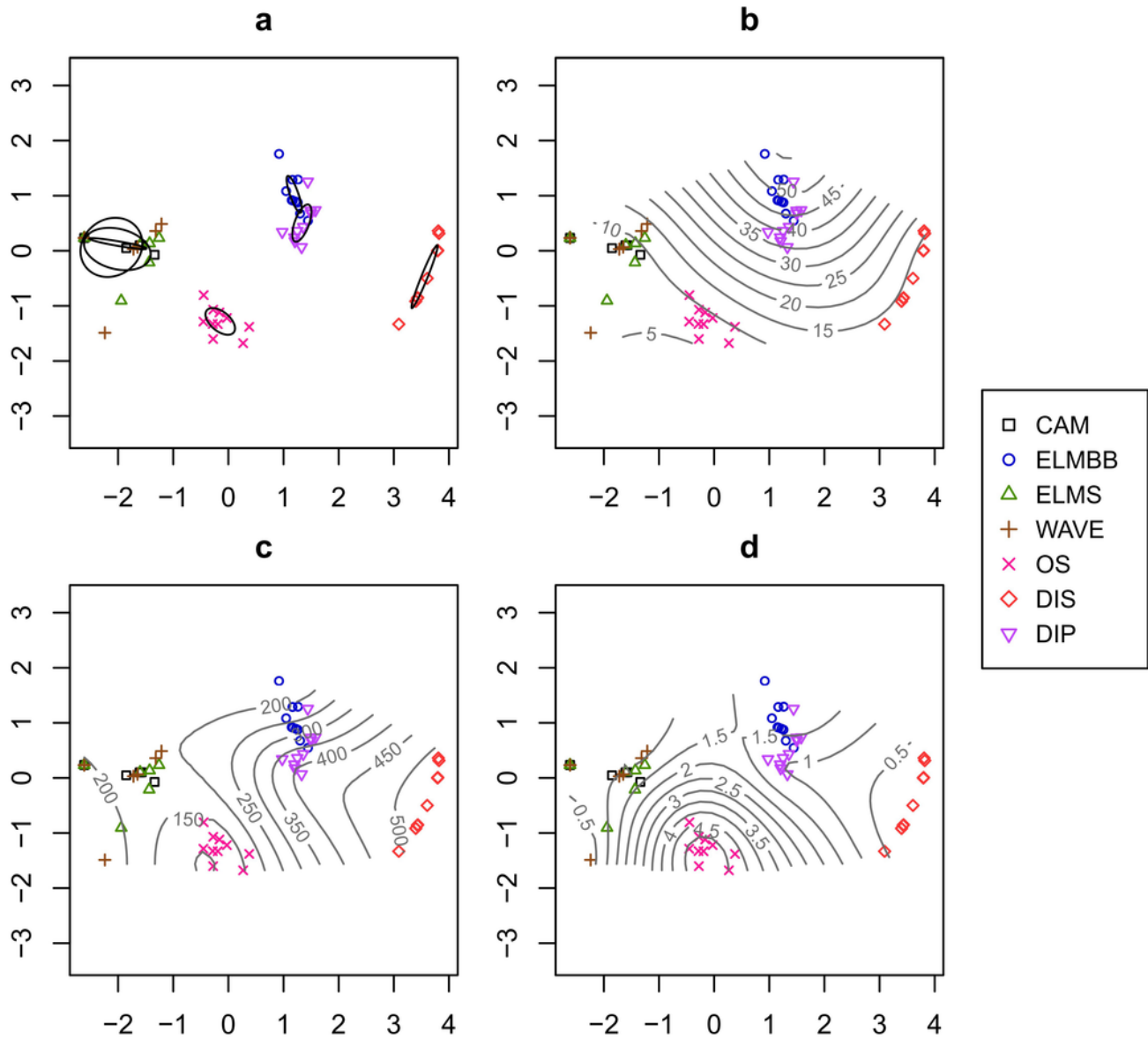
Map of Northern Gulf of Mexico Coast

Map of the sampling sites.

2

Taxa accumulation curves

Taxa accumulation curves for the seven sampling sites.

3

Community composition across sites.

A) An NMDS (non-metric multidimensional scaling) plot of sub-samples of intertidal infaunal invertebrate macrofauna collected from seven sites across the northern Gulf of Mexico (stress = 0.04). The samples comprise four distinct communities (DIS; OS; ELMS+WAVE+CAM; ELMBB+DIP; ANOSIM, R = 0.9989, p = 0.001). Ellipses represent 99% confidence intervals on the centroids of sites. B) NMDS plot of sub-samples with a smooth response surface of salinity values overlaid on the NMDS obtained by the function *ordisurf* in the *vegan* package (Oksanen et al. 2011, vegan, v. 2.0-2). C) NMDS plot of sub-samples with a smooth response surface of median grain size values overlaid. D) NMDS plot of sub-samples with a smooth response surface of total organic content values is overlaid.

4

Summary Figure

Summary of environmental variables, richness and Shannon's diversity measured at each site. A table with exact values can be found in the Supplementary Material.